

Dark energy physics expectations at DES

Marcelle Soares-Santos
(for the DES Collaboration)

Center for Particle Astrophysics, Fermi National Accelerator Laboratory, Batavia IL 60510

E-mail: marcelle@fnal.gov

Abstract. Giving rise to a new and exciting research field, observations of the last 13 years established the accelerated expansion of the Universe. This is a strong indication of new physics, either in the form of a new energy component of the Universe – dark energy – or of theories of gravity beyond general relativity. A powerful approach to this problem is the study of complementary cosmological probes in large optical galaxy surveys such as the Dark Energy Survey (DES). We present the expectations for dark energy physics based on the combination of four fundamental probes: galaxy clusters, weak lensing, large scale structure and supernovae. We show that DES data have constraining power to improve current measurements of the dark energy equation-of-state parameter by a factor of 3–5 and to distinguish between general relativity and modified gravity scenarios.

1. Introduction

The accelerated expansion of the Universe is a well established fact [1], but although the dark energy density Ω_Λ has been determined to a few percent precision, getting at its nature is more challenging. This requires measurements of its equation-of-state, e.g. in terms of the parameters w_0 and w_a of the phenomenological model $w(a) = w_0 + w_a(1 - a)$, and tests of general relativity (GR), e.g. through the γ parameter [2]. Currently w_0 is known to 15% while w_a is largely unconstrained [3] and measurements of γ can not yet distinguish between GR and modified gravity [4, 5]. The Dark Energy Survey (DES, darkenergysurvey.org) [6] is a ground-based photometric survey conceived to significantly improve such measurements by combining [7] galaxy clusters, weak lensing (WL), large scale structure (LSS) and Type Ia supernovae (SNe).

The DES collaboration has built the Dark Energy Camera (DECam) [8], an imaging instrument comprised of 74 250 micron thick CCDs [9] to be installed on the Cerro Tololo Inter-American Observatory (CTIO) 4-meter Blanco telescope [10]. DES will use DECam for 525 nights in the 2012–2017 austral spring/summer to survey a 5000 deg² area of the sky in 5 filters *grizY* up to redshift $z \simeq 1.5$ achieving a volume of 24 $h^{-3}\text{Gpc}^3$, 7 times larger than the largest existing CCD survey of the Universe by volume to date [11]. DES data include: photometric redshifts and shapes of 300 million galaxies, mass and spatial distribution of 100,000 clusters and detection of 4000 Type Ia SNe.

This paper presents the dark energy science prospects for this data set. Section 2 discusses each probe. Section 3 explores the of combination these observables to determine as well w_a and distinguish between GR and modified gravity. Planck priors and statistical errors only are assumed throughout the paper. Conclusions are drawn in Section 4.

2. Probes of cosmic acceleration

2.1. Weak gravitational lensing

Images of distant galaxies show distortions (shear) due to the gravitational bending of their light by structures along the line-of-sight. This weak lensing effect allows us to measure the mass of foreground structures (e.g. galaxy clusters) using shear radial profiles [12, 13]. But the overall cosmic shear field can also be measured, by dividing the survey area in pixels and averaging the galaxy shapes in each pixel. The statistical signal from the cosmic shear field (shear-shear correlation function or, in Fourier space, the power spectrum) allows us to determine [14, 15] the total matter content of the Universe Ω_m and the normalization of matter fluctuations σ_8 . With similar depth and an area 18 times larger than the largest survey used for cosmic shear measurements to date [15, 16], DES will be sensitive to the effect of dark energy on the cosmic shear.

2.2. Galaxy clusters

The number density of the largest gravitationally bound structures (clusters) as a function of redshift and mass is sensitive to the cosmic expansion history because the comoving volume element (geometry) of the Universe is changing and because initially small density perturbations are evolving to form them through gravity against that expansion (growth of structure). Geometry is dominant for clusters at $z < 0.6$ while growth of structures dominates at higher redshifts [1]. Clusters up to $z \simeq 1.0$ can be efficiently detected in DES data [17] as enhancements in the surface density of galaxies using photometric redshifts estimated from their colors to substantially reduce projection effects. The cluster richness, defined as the number of member galaxies, is a good proxy for its mass and the mass-richness relation can be calibrated using weak lensing [12, 13]. Optically selected clusters have been used to measure Ω_m and σ_8 [18]. By obtaining a complete and pure sample of galaxy clusters up to redshift $\simeq 1$ over 5000 square degrees, DES allows us to extend these measurements to constrain dark energy models.

2.3. Large scale structure

Gravity-driven acoustic oscillations of the coupled photon-baryon fluid in the early Universe leave an imprint on the mass power spectrum that can be detected as an excess in the galaxy-galaxy correlation function at a characteristic scale. The scale of the oscillations is that of the sound horizon at the epoch of recombination, known through the power spectrum of cosmic microwave background anisotropies measured by WMAP [19] to be 146.2 ± 1.1 Mpc. The corresponding scale on the galaxy angular power spectrum is a geometric probe of the cosmic expansion history and has been used to measure dark energy [20, 21]. DES will use LSS to perform such measurements from its data set.

2.4. Supernovae

Type Ia SNe can be used as standard candles to probe the cosmic acceleration through the magnitude-redshift relation (the Hubble diagram). Their progenitors, carbon-oxygen white dwarfs accreting mass from a companion star, explode producing ^{56}Ni (which later decays into ^{56}Co) at a rate directly related to their peak luminosity [1]. The first direct evidence for cosmic acceleration came from SNe Ia, and of the four probes, they have provided the strongest constraints on the dark energy equation-of-state parameter to date [3]. By observing about 10 times more SNe, DES will significantly improve such measurements [22].

3. Combined constraints

The cosmological techniques explored by DES have constraining power to probe dark energy with high precision individually, but it is the combination of these complementary probes that

can produce the best results. Such combinations have been explored to some extent (e.g., SNe+CMB+LSS [3]) but DES is the first experiment to combine all four probes from the same data set, being able to achieve percent-level uncertainty on w_0 and, in addition, measure w_a . By combining the four probes we can measure w_0 at 5% and w_a at 30% uncertainty level, as shown in Fig. 1, improving the constraints on the dark energy equation-of-state $w(a)$ by a factor of 3-5 with respect to current experiments.

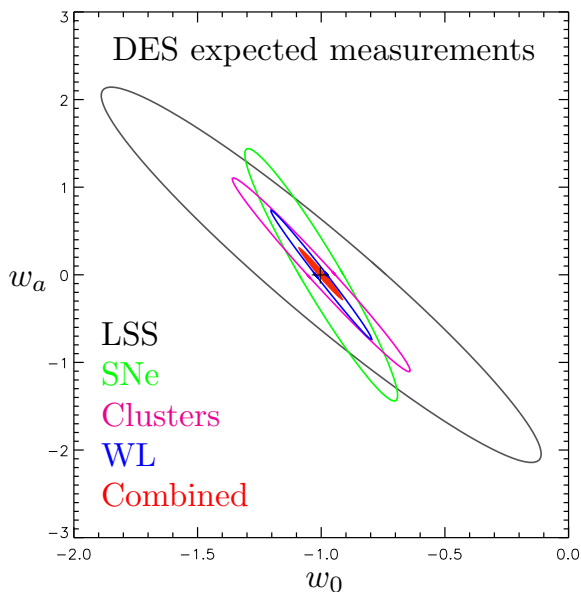


Figure 1. Forecast for 1σ constraints on dark energy parameters from the DES probes, including only statistical errors and assuming $w_0 = -1$, $w_a = 0$ as the true model [23, 24]. Each individual constraint uses Planck priors. The supernovae constraint includes an 8% prior on H_0 . The constraints from the combination of the four probes (solid red region) correspond to uncertainties in w_0 and w_a of 5% and 30% respectively.

Our data set also allows us to distinguish between GR and certain modified gravity theories, by measuring the parameter γ . This can be achieved using a multi-dimensional consistency test of the four dark energy probes [24]. An inconsistency would result in contours slightly miscentered with respect to each other. Such analysis, performed on DES data, can distinguish between $\gamma = 0.55$ (GR case) and $\gamma = 0.68$ (approximately the value for the Dvali-Gabadadze-Porrati (DGP) braneworld model [25]) at a 99.1% level [24].

4. Conclusions

DES is a photometric survey designed to shed light on the dark energy problem through four complementary methods (LSS, SNe, Clusters and Weak Lensing). Commissioning of the DES imaging instrument, DECam, is imminent. The survey is scheduled to start in the second semester of 2012, take data over 5 years and make available to the astronomical community a data set of unprecedented depth for its area (5000 deg^2 up to redshift $\simeq 1.5$). This rich data set has the potential for a variety of studies, from galaxy evolution to cosmology. The prospects for dark energy science are highlighted in this paper with focus on the key analyses of the four cosmological probes to improve current measurements of the equation-of-state parameter $w(a)$ by a factor of 3-5. DES also has the potential to distinguish between GR and modified gravity theories by measuring, for instance, deviations of the parameter γ from the GR value $\gamma = 0.55$ at high significance level.

Acknowledgments

Funding for the DES Projects has been provided by the U.S. Department of Energy, the U.S. National Science Foundation, the Ministry of Science and Education of Spain, the Science and Technology Facilities Council of the United Kingdom, the Higher Education Funding Council for

England, the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign, the Kavli Institute of Cosmological Physics at the University of Chicago, Financiadora de Estudos e Projetos, Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro, Conselho Nacional de Desenvolvimento Científico e Tecnológico and the Ministério da Ciência e Tecnologia, the Deutsche Forschungsgemeinschaft and the Collaborating Institutions in the Dark Energy Survey.

The Collaborating Institutions are Argonne National Laboratories, the University of California at Santa Cruz, the University of Cambridge, Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas-Madrid, the University of Chicago, University College London, DES-Brazil, Fermilab, the University of Edinburgh, the University of Illinois at Urbana-Champaign, the Institut de Ciències de l'Espai (IEEC/CSIC), the Institut de Física d'Altes Energies, the Lawrence Berkeley National Laboratory, the Ludwig-Maximilians Universität and the associated Excellence Cluster Universe, the University of Michigan, the National Optical Astronomy Observatory, the University of Nottingham, the Ohio State University, the University of Pennsylvania, the University of Portsmouth, SLAC, Stanford University, the University of Sussex, and Texas A & M University.

References

- [1] Frieman J A, Turner M S and Huterer D 2008 *ARA&A* **46** 385–432 (*Preprint* 0803.0982)
- [2] Linder E V 2005 *Phys. Rev. D* **72** 043529 (*Preprint* arXiv:astro-ph/0507263)
- [3] Sullivan M *et al.* 2011 *ApJ* **737** 102 (*Preprint* 1104.1444)
- [4] Thomas S A, Abdalla F B and Weller J 2009 *MNRAS* **395** 197–209 (*Preprint* 0810.4863)
- [5] Reyes R *et al.* 2010 *Nature* **464** 256–258 (*Preprint* 1003.2185)
- [6] Abbott T *et al.* 2005 (*Preprint* astro-ph/0510346)
- [7] Albrecht A *et al.* 2006 (*Preprint* astro-ph/0609591)
- [8] Flaughar B *et al.* 2010 *Proc. SPIE* **7735** 77350D
- [9] Estrada J *et al.* 2010 *Proc. SPIE* **7735** 77351R
- [10] Abbott T *et al.* 2006 *Proc. SPIE* **6267** 77353I
- [11] Thomas S, Abdalla F and Lahav O 2011 *PRL* **106** 241301 (*Preprint* 1012.2272)
- [12] Johnston D E *et al.* 2007 *ApJ* **656** 27–41 (*Preprint* astro-ph/0507467)
- [13] Simet M *et al.* 2011 *ApJ submitted* (*Preprint* 1111.6621)
- [14] Fu L *et al.* 2008 *A&A* **479** 9–25 (*Preprint* 0712.0884)
- [15] Lin H *et al.* 2011 *ApJ submitted* (*Preprint* 1111.6622)
- [16] Annis J *et al.* 2011 *ApJ submitted* (*Preprint* 1111.6619)
- [17] Soares-Santos M *et al.* 2011 *ApJ* **727** 45 (*Preprint* 1011.3458)
- [18] Rozo E *et al.* 2010 *ApJ* **708** 645–660 (*Preprint* 0902.3702)
- [19] Jarosik N *et al.* 2011 *ApJS* **192** 14 (*Preprint* 1001.4744)
- [20] Percival W J *et al.* 2010 *MNRAS* **401** 2148–2168 (*Preprint* 0907.1660)
- [21] Blake C *et al.* 2011 *MNRAS* **1598** (*Preprint* 1108.2635)
- [22] Bernstein J P *et al.* 2011 (*Preprint* 1111.1969)
- [23] <http://www.darkenergysurvey.org/reports/proposal-standalone.pdf>
- [24] Shapiro C *et al.* 2010 *Phys. Rev. D* **82** 043520 (*Preprint* 1004.4810)
- [25] Dvali G, Gabadadze G and Porrati M 2000 *Phys. Lett. B* **485** 208–214 (*Preprint* hep-th/0005016)